In the Matter of	)	
	)	
CARRIER CURRENT SYSTEMS	)	ET Docket No. 03-104
INCLUDING BROADBAND OVER POWER	)	
LINE SYSTEMS	)	
	)	
AMENDMENT OF PART 15 REGARDING	)	ET Docket No. 04-37
NEW REQUIREMENTS AND	)	
MEASUREMENT GUIDELINES FOR	)	
ACCESS BROADBAND OVER POWER LINE	)	
SYSTEMS	)	

To: The Commission

REPLY COMMENTS BY JAMES K. BOOMER

The following reply comments are respectfully submitted in response to the *Notice of Proposed Rule Making* (The Notice), FCC 04-29, released on February 23, 2004, and the submittals of ARRL and IEEE on May 3, 2004.

I. Introduction

The ARRL, the IEEE, the author, and many others have respectfully noted their concerns about BPL electromagnetic compatibility (EMC) issues, and the FCC's apparent desire to modify its regulations to accommodate Broadband over Power Line (BPL) as soon as possible. Indeed, both the ARRL and the IEEE have expressed surprise and disappointment at the FCC's seeming rush to arrive at a BPL implementation decision without the attendant up-front research and analysis to support such a decision.

Furthermore, when one looks objectively at broadband data capability, it is difficult to conclude that there is really a market for BPL, because there is a mound of work yet to be done to prove the basic feasibility of an EMC BPL *prior to any implementation decisions*. And this work consumes valuable time, personnel, and monetary resources, while, concurrently, today's fiber optic cable, coaxial cable, satellite, and wireless broadband systems markets are exponentially expanding. Accordingly, the costs for these services will continue to decrease, thereby increasing the availability to more consumers.

Thus, the author concludes that by the time all of the BPL issues are properly identified and potentially resolved, the market for it will have evaporated.

II. Summary

BPL is a very complex concept that must have engineering, licensing, and regulatory analyses similar to cellular telephone and wireless systems to resolve all technical, regulatory, and (probable) licensing issues before proceeding. This paper underscores the many presently unanswered questions and unresolved issues.

There are six major unresolved BPL-related variables, all of which are random:

1. Random Variable: Distance between power lines and licensed station antennas

2. Random Variable: Licensed station antenna directivity gain and orientation

3. Random Variable: Directivity gain and BPL power radiated from power lines

4. Random Variable: Licensed station modulation, transmitter output power, and total radiated power from its antenna system

5. Random Variable: On many occasions, the external noise will be less than the rural Alaskan winter environment shown in Figure 5-2, page 5-13, of the NTIA Report 04-413

6. Random Variable: A licensed station's operating frequency

FCC regulations forbid unlicensed systems from interfering with licensed stations' operations.

In view of these facts, supported by the information that follows, the present approach to provide broadband capability using the power lines as a transmission medium has major electromagnetic compatibility (EMC) issues that must be resolved *prior to a go/no-go decision*. Unlike other new concepts, such as cellular telephone and today's wireless systems, the current BPL approach is sadly devoid of the mandatory analyses to prove or disprove the concept *prior to fielding equipment*. Indeed, the current approach is unfortunately an unlicensed "let's try it and see what happens!" proposition. It is an invitation to massive EMC problems, misunderstandings, and litigation unless all of the issues are clearly delineated and resolved prior to fielding equipment and systems.

In previous submittals to the FCC (ref. 04-29) on this subject, the author has recommended maximum field strength limits to assure BPL-licensed station EMC. However, as a result of further consideration of the technical, regulatory, and market issues, the author now recommends that BPL be abandoned because of the massive EMC, social, and legal issues it creates, for which there are no straightforward solutions.

Indeed, by the time the major BPL issues are truly identified and resolved, the market for BPL will have evaporated because of the exponential growth of today's existing cable, satellite, and wireless broadband systems markets.

III. General Comments

There are currently a variety of opinions and disagreements on EMC, BPL field strength limits and measurement methods. In some approaches, measurements are taken in the near field of the power lines, which are actually radiating antenna arrays. Additionally there are virtually an infinite number of outdoor and indoor power line (radiating antenna) configurations with varying directivity gains, which further complicates the notion of specifying field strength limits. This is clearly evident in The National Telecommunications and Information Agency's efforts to date, which have culminated in NTIA Report 04-413, "Potential Interference From Broadband Over Power Lines (BPL) Systems to Federal Government Radio Communications at 1.7-80 MHz."

Importantly, ARRL reminds us of one key fundamental fact: the FCC Part 15 rules for unlicensed radiators are intended for so-called point source radiators (i.e. a piece of radio equipment, a computer, a television set, a VCR, a telephone, etc.), _not_ sources that distribute radiated energy over a large area, such as a BPL system—i.e. power lines excited with BPL energy.

These considerations clearly lead us to the correct conclusion:

If, through engineering, regulatory, licensing and market research, BPL is determined to be a viable concept, it must be licensed, and have specific frequency and power output allocations (including spurious radiations) consistent with worldwide organizations such as ITU, etc. This approach assures EMC, and alleviates all of the current issues associated with BPL, and licensed station compatibility.

Some BPL suppliers propose more than 10 Megabits per second (Mbps) throughput, which means that the signals will consume at least 10 MHz of spectrum. If 10 MHz chip rate pseudo-noise spread spectrum (PNSS) modulation is used, the system will consume more than 20 MHz of spectrum. The problem then is, from where do the required frequency allocations come?

IV. Technical Analysis

The following analysis underscores the EMC problem with BPL. In this analysis we assume that the BPL signal is essentially band-limited pseudo-random noise, such as is the case with spread spectrum systems, which provide large throughputs. If the BPL interference is coherent, we must use a different approach to evaluate EMC, taking into account the receiver's cross modulation, intermodulation, and demodulator characteristics.

A. Maximum Allowable BPL Interference to Licensed Radio Station Receiving Systems

To realistically address BPL-licensed station EMC, we must assume quiet external noise conditions because the noise level at any instant is a random variable, and EMC must exist in this environment. For example, there may be EMC when the external noise level is, say, 70 dB above thermal (KT_o), because received interference from BPL may be substantially below, and therefore masked, by this system noise level. However when the external noise is, say, 20 dB above thermal, there may not be EMC because BPL radiated power may cause an excessive increase in the receiving system noise floor, thereby reducing the carrier-to-noise ratio from the desired signal.

The noise output power density from a receiver with no added input noise is:

$N_o = KT_oF$ Watts/Hz   Equation 1

Where,

N_o=Noise power, Watts/Hz

K= Boltzmann's Constant=1.38×10^{-23} Joule per degree Kelvin

T=Temperature in degrees Kelvin (standard temperature, T_o=290 degrees Kelvin)

F=Receiver noise factor (power ratio)

Since we are ultimately concerned with ratios, we assume the receiver has unity gain, hence the absence of the receiver gain in Equation 1. Clearly, we could include receiver gain in our analysis, but the gain term cancels out, and thus need not be carried along on all calculations.

We are interested in how much the receiver noise level is raised by externally induced noise, because for every dB increase in receiver output noise level, we have a corresponding dB decrease in carrier-to-noise ratio from a desired signal source.

Let us characterize externally induced noise level as $mKT_o.$

Then, the receiver output noise power density with this externally induced noise is,

$N_o' = KT_oF + mKT_o = KT_o(F+m)$ Watts/Hz   Equation 2

The increase in receiver output noise power density from the addition of this externally induced noise is,

$N_o'/N_o = KT_o(F+m)/KT_oF = (F+m)/F = 1+m/F$ (power ratio)   Equation 3

The referenced NTIA Report, Volume I, Figure 5-2, page 5-13, lists external noise data for both noisy and quiet environments. For example, data from the graph in Figure 5-2 show that the noise level associated with a quiet Alaska winter environment is as follows:

Freq. (MHz)	Noise Level (dBW/Hz)	Noise Level (dB-KT$_o$/Hz)
1.8	-155	49
3.5	-160	44
7	-165	39
10	-173	31
14/18	-178	26
21/24	-183	21
28	-185	19

Table-1 External Noise Level-Quiet Environment (Data Source: See Text)

The right-hand column in Table 1 is simply the output noise power density referred to thermal (KT$_o$) in dB. To demonstrate the methodology for specifying the maximum allowable interference from BPL, consider a collocated receiving system with a 6 dB noise figure (noise factor of 3.98), operating at 10 MHz.

From Equation 1, the receiver noise output power density without externally induced noise is:

N_o=KT$_o$F Watts/Hz

K= Boltzmann's Constant=1.38x10^{-23} Joule per degree Kelvin

T$_o$=Standard temperature=270 degrees Kelvin

F= Noise factor= 3.98 (power ratio)

Then,

N_o=(1.38x10^{-23})(290)(3.98)= 1.59x10^{-20} Watt/Hz ($\approx$ -198 dBW/Hz)

From Table 1, the external noise at 10 MHz is 31dB-KT$_o$ (31 dB above thermal).

From Equation 3, we have:

$N_o'/ N_o =1+m/F,$

So,

N_o'/ N_o (dB)=10log (1+m/F)

$m=10^{(db-KT_o /10)}$

Thus for external noise 31 dB above thermal,

$m=10^{(31/10)}=1258.93,$

So, from Equation 3,

N_o'/ N_o (dB)=10log(1+1258.93/3.98)=10log $317.31 \approx 25$dB

Thus external noise power density 31 dB above thermal raises the receiver noise power density floor 25 dB.

Threfore, with the above external noise, the receiver noise floor becomes:

N_o'= -198+25= -173 dBW/Hz (5.01x10^{-18} Watt/Hz)

For EMC, BPL interference must not raise the licensed station's receiver noise floor more than 1 dB. This requirement stems from the fact that a 1 dB decrease in carrier-to-noise ratio will increase a modern, coded (e.g. convolutional rate one-half code with maximum likelihood soft decision detection) binary phase shift keying (BPSK) data system's bit error rate (BER) more than an order of magnitude, as shown in Figure 1, which includes
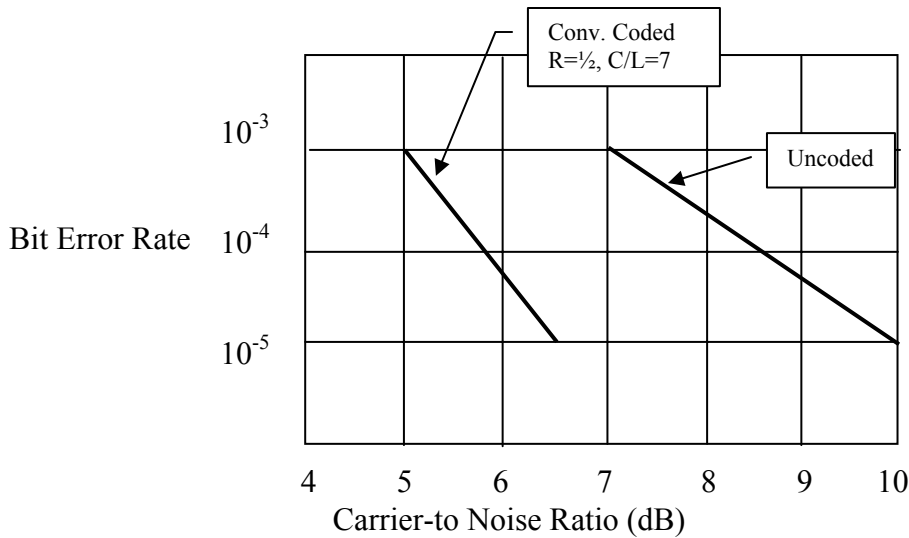

Figure 1-Binary Phase Shift Keying (BPSK) Bit Error Rate vs. C/N Ratio

the typical implementation margin. A bit error rate (BER) of 10^{-3} is considered the maximum for reliable data communications, however, it would be better if the carrier-to-noise ratio were not degraded by more than 0.5 dB, which would give us a better BER in the presence of interference.

With a 1 dB increase in noise, the new noise floor is:

N_o'(dBW)+1 dB=N_o''= -173+1= -172 dBW/Hz (6.31×10^{-18} Watt/Hz)

We then calculate the maximum allowable additional noise power density input to the receiver for EMC:

N_{ext}=N_o''− N_o' Watts/Hz=6.31×10^{-18}-5.01×10^{-18}= 1.3×10^{-18} Watt/Hz (-178.9 dBW/Hz)

Notice in the above analysis, we have not considered the licensed station's receiving antenna, which could have negative directivity gain, or very high positive directivity gain (with respect to an isotropic radiator or a dipole). In addition, we have not characterized the BPL signal power spectra or levels, or the directivity gain of the power lines with BPL signal power applied to them. Finally, we have not discussed the signal energy that BPL systems will receive from licensed station transmitters.

Clearly, then, there are six major unresolved BPL-related variables, all of which are random:

1. Random Variable: Distance between power lines and licensed station antennas

2. Random Variable: Licensed station antenna directivity gain and orientation

3. Random Variable: Directivity gain and BPL power radiated from power lines

4. Random Variable: Licensed station transmitter modulation, output power, and total radiated power from its antenna system

5. Random Variable: On many occasions, the external noise may be less than the rural Alaskan winter environment shown in Figure 5-2, page 5-13, of the NTIA Report 04-413

6. Random Variable: A licensed station's operating frequency

Freq. (MHz)	Rcvr. N.F. (dB)	Noise Floor, N_o (dBW/Hz)	Ext. Noise (dB-KT_o)	Noise Floor w/Ext. Noise (dBW/Hz)	Max. Allow. BPL Intf. (dBW/Hz)
1.8	10	-193.98	49	-154.97	-160.84
3.5	6	-197.98	44	-159.98	-165.84
7	6	-197.98	39	-164.97	-170.84
10	6	-197.98	31	-172.94	-178.81
14	6	-197.98	26	-177.87	-183.74
18	6	-197.98	26	-177.87	-183.74
21	6	-197.98	21	-182.65	-188.51
24	6	-197.98	21	-182.65	-188.51
28	6	-197.98	19	-184.46	-190.33

Table-2 Maximum Allowable Interference to Licensed Station Receiver (See Text)
The above analysis methodology has been used to prepare Table 2, using the Table 1
external noise numbers.

We can use EZNEC antenna modeling software to determine the maximum allowable
BPL output power output to the electrical transmission lines. Furthermore, we can use the
same modeling technique to determine the level of interference the BPL system will
encounter in the presence of a licensed station transmitted signal.

The antenna model we have chosen is shown in Figure 2, which essentially emulates one
system described in NTIA Report 04-413, namely, three 10 mm diameter power lines,
340 meters long, spaced 60 cm. apart, and 8.5 meters above the ground. Each line is
terminated in 50 Ohms at each end, and one outside line is fed at the center. In addition,
we collocated a half-wave dipole 30 meters from the three-wire electrical power
transmission system, and at a height of 8.5 meters above the ground. We choose a 30-
meter separation because the ARRL has determined that a significant number of radio
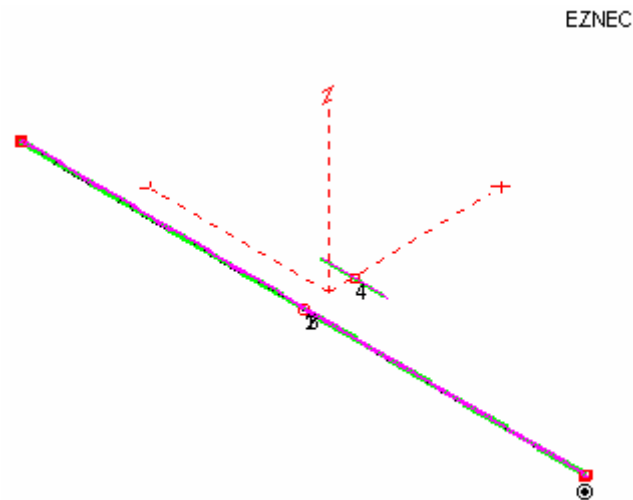amateurs' antennas are collocated at this distance.

Figure 2-BPL-Licensed Station Antenna Modeling Geometry

BPL Transmit-Licensed Station Receive Analysis (3.5 MHz)

The licensed station dipole center is lined up with the center of the power line system
because the maximum directivity gain is near right angles to the power lines' orientation,
as shown in Figure 3. That is, if the power lines are oriented north to south, the
maximum gain of the power line array is near east to west. Note in Figure 3 that the
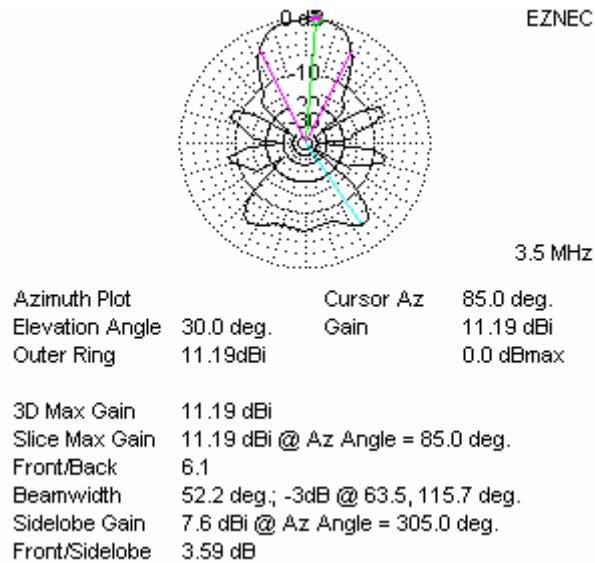power line array

Figure 3-Power Lines' Far Field Directivity Pattern With Licensed Station Half-wave Dipole Collocated 30 meters Away (See Text)

has a maximum directivity gain of 11.19 dBi at a 30-degree elevation angle, and at 85 degrees azimuth with respect to the power lines' direction.

> **With the geometry of Figure 2, at 3.5 MHz, a BPL power output of 2.7×10^{-15} Watt/Hz (-145.69 dBW/Hz, or –115.69 dBm/Hz) to the power line system results in an interference power of –165.84 dBW/Hz to a licensed station receiver connected to a half-wave dipole antenna collocated 30 meters from the power lines. This is the maximum interference level permitted in accordance with Table 2. If the BPL system bandwidth is, say, 10 MHz, and its signal structure is essentially band-limited pseudo-random noise, its maximum allowable output to the power line system is $-145.69 + 10 \log 10^7 = -75.69$ dBW (2.698×10^{-8} Watt) in a 10 MHz bandwidth.**

Licensed Station Transmit-BPL Receive Analysis

With the basic geometry of Figure 2, we excite the half-wave dipole with 1500 Watts of power, and determine how much power is received by the BPL system coupled to the center of one of the three power lines.

Figure 4 shows the far field directivity pattern of the half-wave dipole when it is spaced 30 meters from the power line system.

With the geometry of Figure 2, at 3.5 MHz, 1,500Watts output to a half wave dipole collocated 30 meters from the power line system, results in a received power by the BPL system of 0.2604 Watt (-5.84 dBW, or +24.16 dBm). Its interference from, say, a single sideband (SSB) voice transmitter with a bandwidth of 2.8 kHz will be –5.84 dBW in this bandwidth at 3.5 MHz. So, in this 2.8 kHz bandwidth, the BPL system will be operating with a signal-to-interference (S/I) ratio of: –79.65-(-5.84)= -73.81 dB. The performance of BPL with this coherent interference will depend upon its linearity and dynamic range—i.e. this narrowband signal may desensitize the BPL system.
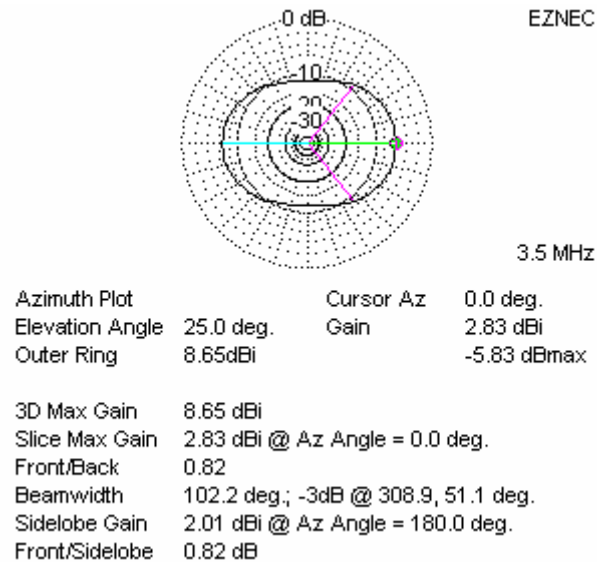

Figure 4- 3.5 MHz Half-wave Dipole Azimuth Pattern When 30 Meters From Power Lines (See Text)

The directivity gain of the half-wave dipole is greater at higher angles than shown in Figure 4.

Antenna Modeling Summary

Clearly, the directivity gain of the power line system will be different at different frequencies and with different geometries than shown in Figure 2. Additionally, many licensed stations use antenna systems with substantially higher directivity gain arrays at 3.5 MHz and at other frequencies. Thus, the maximum allowable BPL output power for EMC with 30 meters separation will vary with frequency and antenna directivity gain.

In fact, from the above single example:

We see that we can be assured of EMC only if we evaluate every combination of power outputs, modulations, and radiating system directivity gains for both the BPL and licensed station systems. This is a daunting task to say the least!

V. Conclusion

> **The present approach to provide broadband capability using the power lines as a transmission medium has major electromagnetic compatibility (EMC) issues that must be resolved *prior to reaching a go/no-go decision to field such a system*.**

> **Unlike other new concepts, such as cellular telephone and today's wireless systems, the current BPL approach is sadly devoid of the mandatory engineering analysis to prove or disprove the concept *prior to fielding equipment*. Indeed, the current approach is unfortunately a "let's try it and see what happens!" proposition. It is an invitation to massive misunderstanding and litigation unless the issues are clearly delineated and resolved prior to fielding equipment and systems.**

The current BPL approach has a basic flaw. It is devoid of the required engineering and regulatory analysis that proves or disproves the soundness of the concept. Some preliminary measurements and analyses have been conducted with disagreement among parties on the interference potential of the BPL system.

The American Radio Relay League has identified a realistic scenario:

1. Suppose a person is unable to operate his or her BPL system, and discovers that there is a Radio Amateur living nearby, and that the reason the BPL system isn't working is because of the presence of the Radio Amateur's transmitter signal. Suddenly, we have a human relations issue. The BPL user will rightly claim that he or she is paying for a service that isn't available when the Radio Amateur's station is transmitting. Similarly, the Radio Amateur will rightly claim that his or her equipment meets FCC requirements, and that he or she is entitled to operate the equipment. The same situation can exist when BPL is interfering with a Radio Amateur's receiver system.

2. In this real world example, the FCC's intent for the BPL supplier to solve the problem seems impractical. For example, in the above scenario, will the BPL supplier come to the BPL user's house during the nighttime and "fix" the above problem? How would the supplier go about determining what the problem really is? Common sense tells us that this is a "real-time" scenario, where the BPL user and the Radio Amateur both want to use their equipment, and an immediate solution to the problem is virtually impossible.

Clearly, as with all new systems that use radio spectrum, a detailed engineering analysis is mandatory to determine the feasibility of the BPL concept before any decisions are made to field the system.

> **Recall that AT&T's Bell Laboratories and NT&T spent years researching the cellular telephone concept before they proved its feasibility. In addition, frequency allocations, FCC regulations and licensing were major considerations for fielding such a system.**

> **BPL is a very complex concept that must have an engineering, licensing, and regulatory analysis similar to cellular telephone and wireless systems to resolve all technical, regulatory, and (probable) licensing issues before proceeding. As noted earlier in this paper, there are many unanswered questions and unresolved issues.**

> **It is hoped that this paper will help illuminate some of the key BPL issues, and also will help government and industry decision makers understand the necessity for objective systematic engineering, frequency allocation, licensing, and market analyses to determine the true feasibility of BPL, particularly in today's rapidly expanding cable-, satellite-, and wireless-based broadband market.**

James K. Boomer Credentials

- Electronics Engineer, BSEE, 1954 from the University of Nebraska

- Radio and Communication Systems Design Engineer, Staff Engineer and Project Engineer, Collins Radio Company, Cedar Rapids, Iowa, 1954 to 1964

- Communication Systems Project Engineer and Design Engineer for National Cash Register Company, Dayton, Ohio, 1964 to 1966

- Communication Systems Staff Engineer, Design Engineer, Project Engineer, and Engineering Section Manager at Magnavox Company (now Raytheon), 1966-2000

- Marketing Product Manager, Communication Systems, Magnavox Company (now Raytheon), 1978-2000.